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DeLaCruz

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(54) **MIXED-SIZED PILLARS THAT ARE
PROBEABLE AND ROUTABLE**

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See application file for complete search history.

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H01L 2924/207; G01R 31/28

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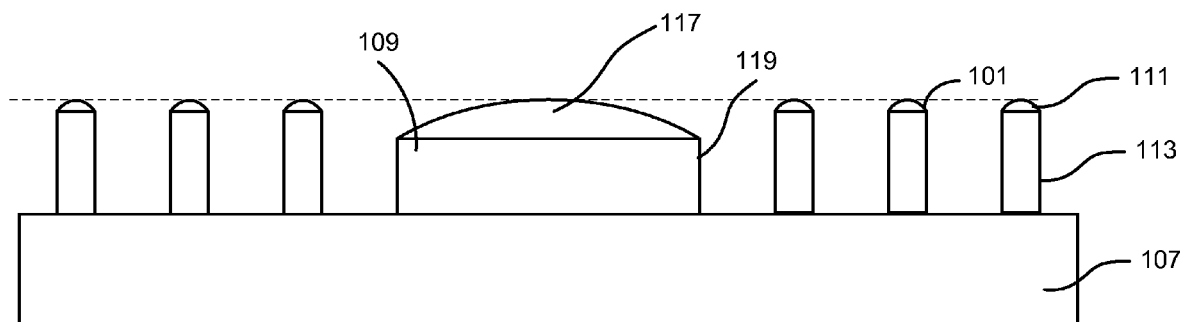
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(57) **ABSTRACT**

An integrated circuit with probeable and routable interfaces is disclosed. The integrated circuit includes multiple micro-pillars that are attached to the surface of the integrated circuit, and multiple macro-pillars also attached to the surface of the integrated circuit. The micro-pillars provide an electrical interface to the integrated circuit during regular operation. The macro-pillars provide an electrical interface to the integrated circuit both during regular operation and during testing of the integrated circuit.

18 Claims, 9 Drawing Sheets



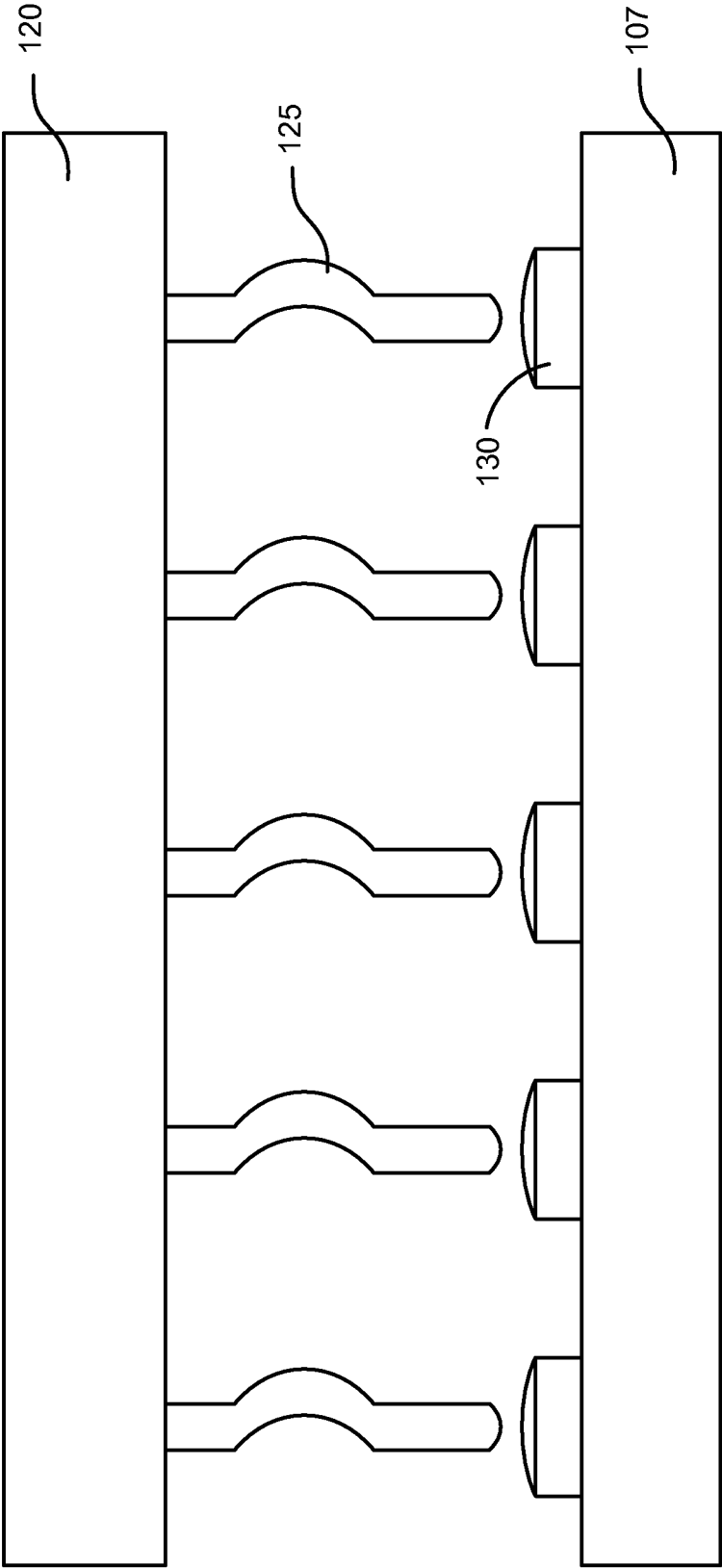


FIG. 1A

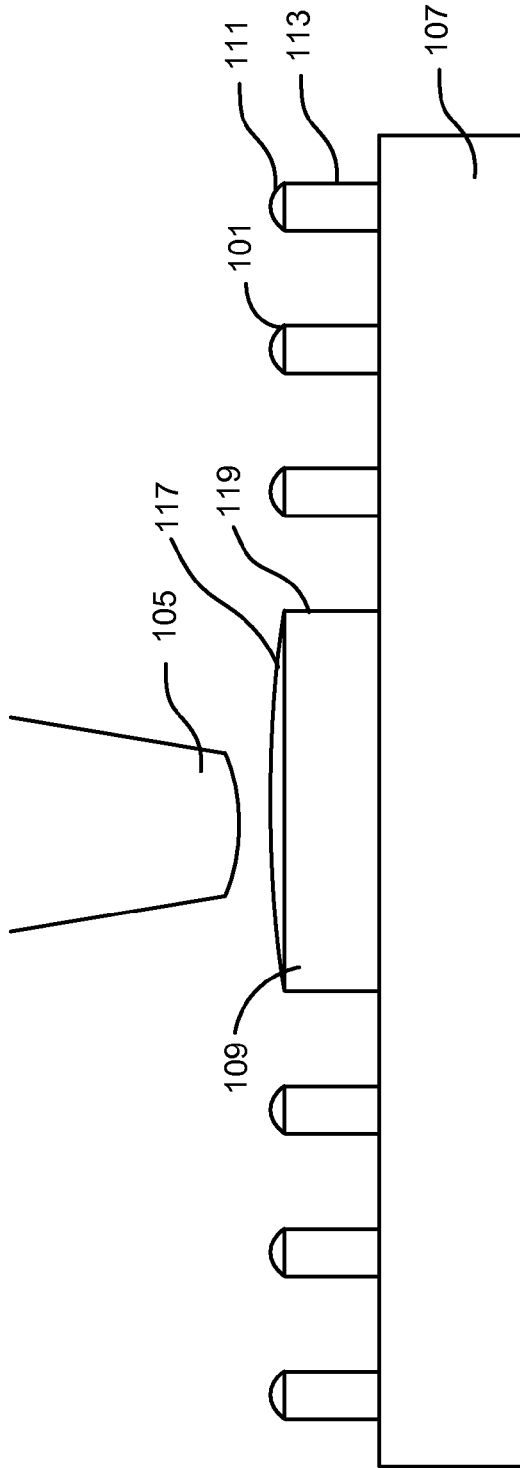


FIG. 1B

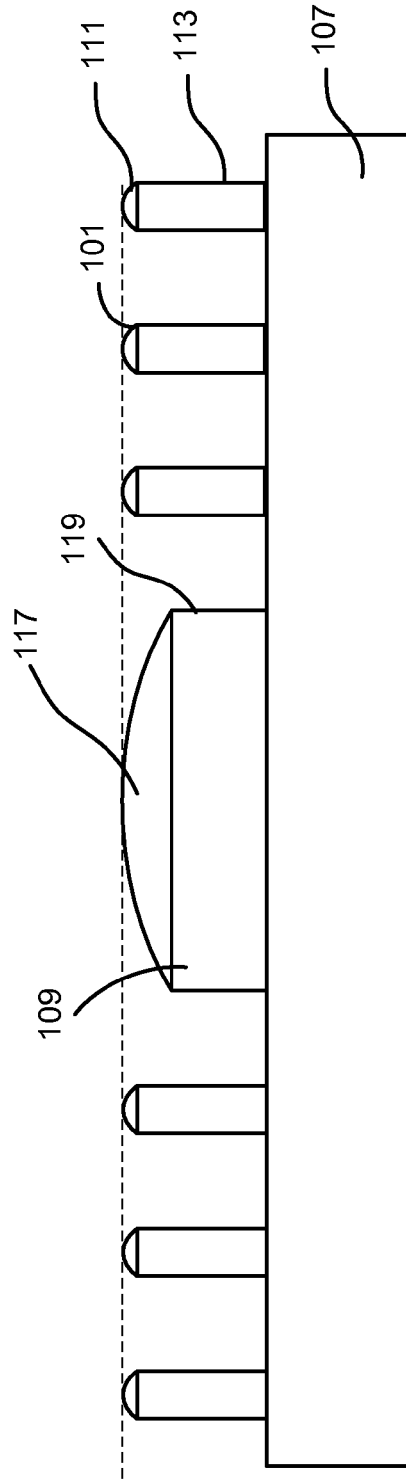


FIG. 1C

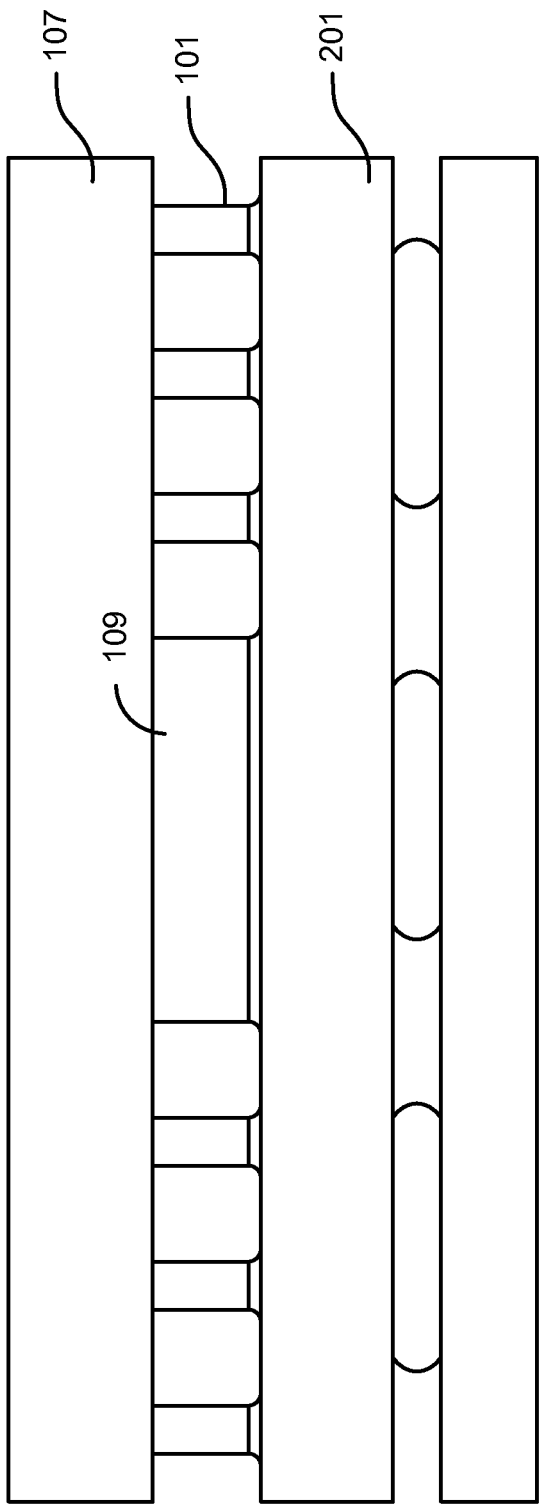
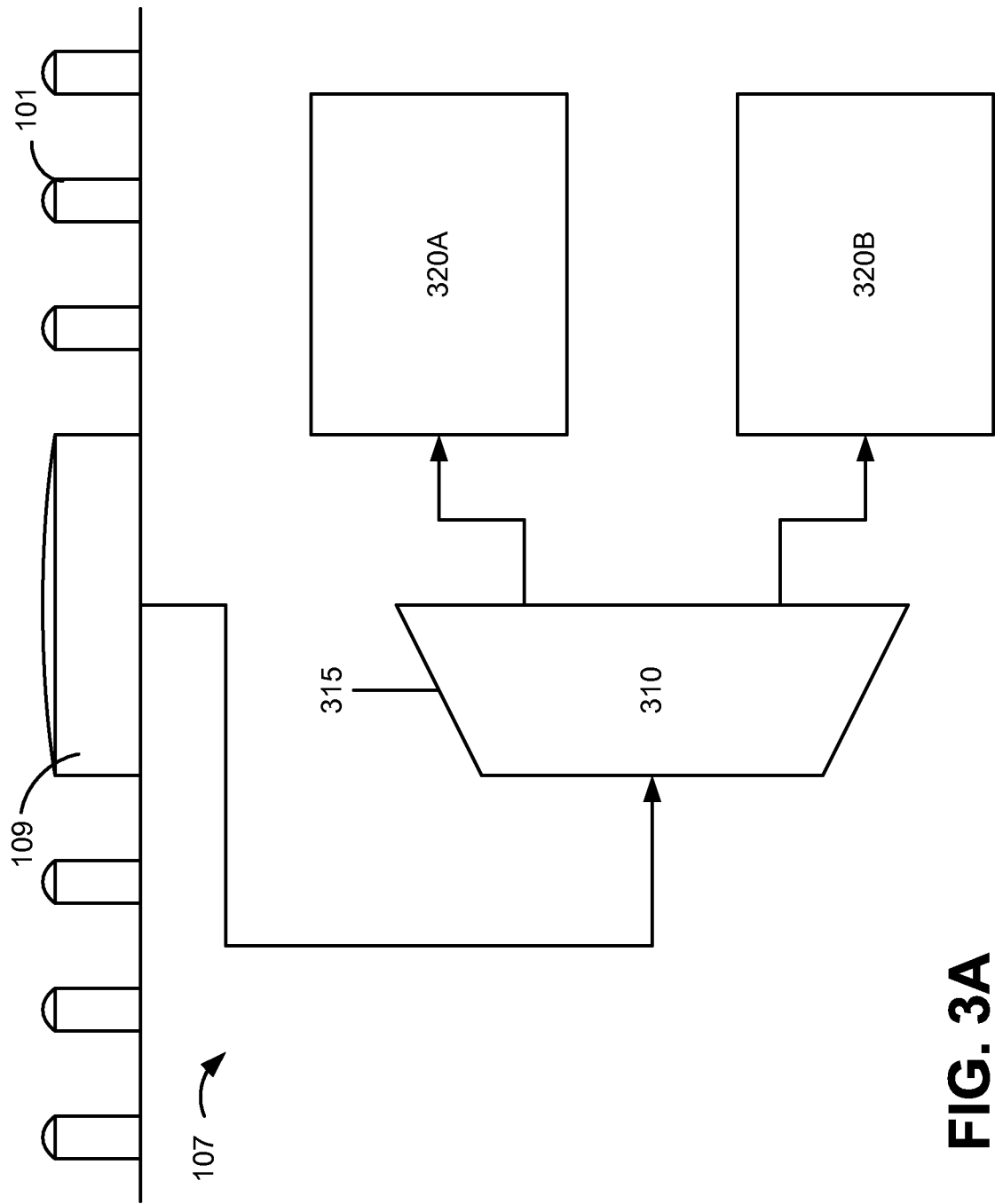


FIG. 2



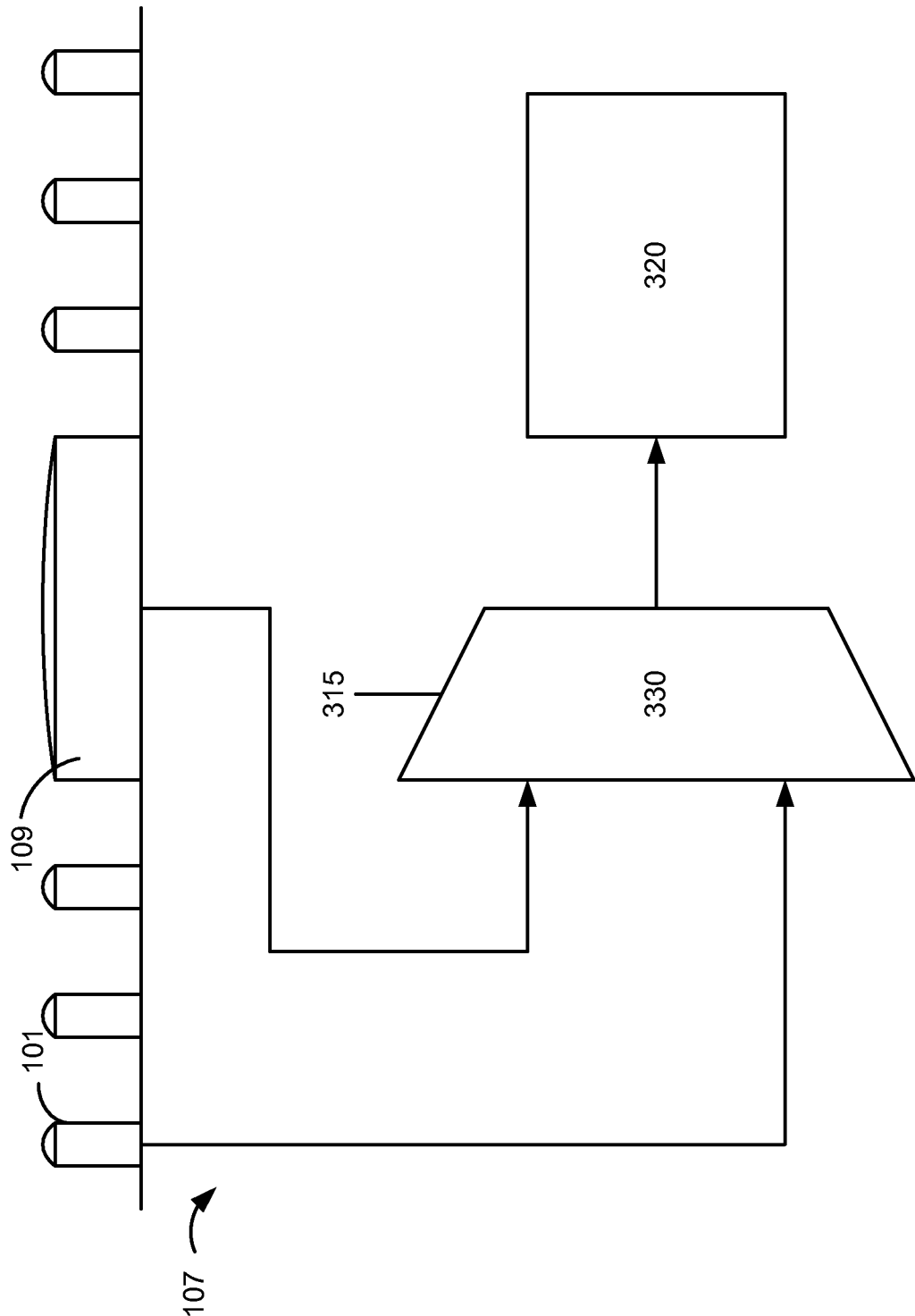


FIG. 3B

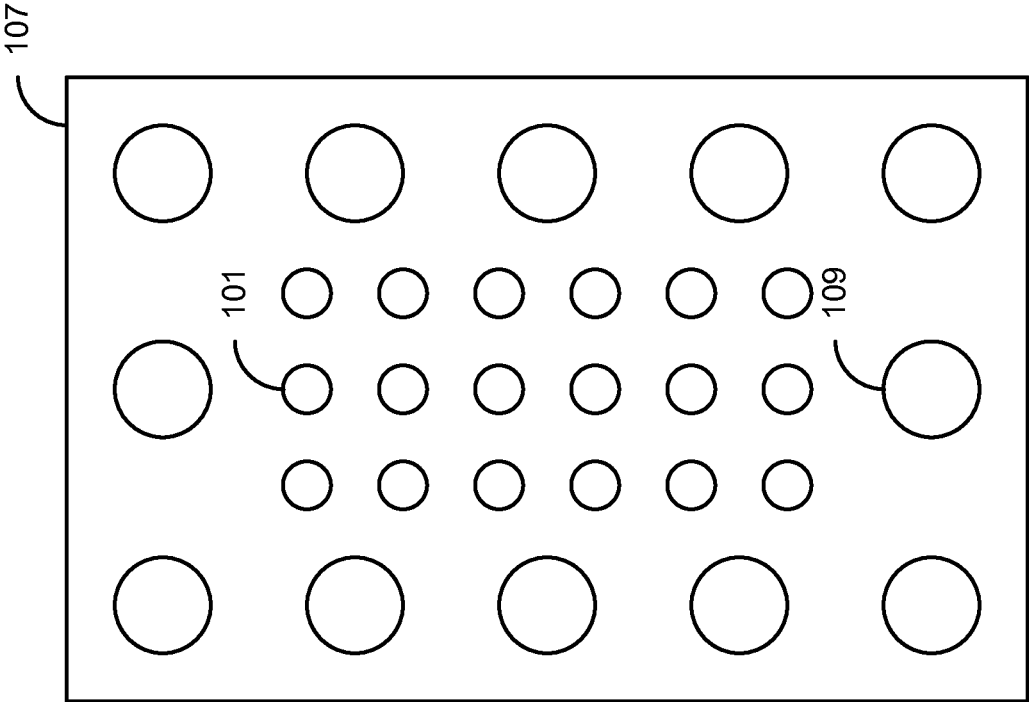


FIG. 4B

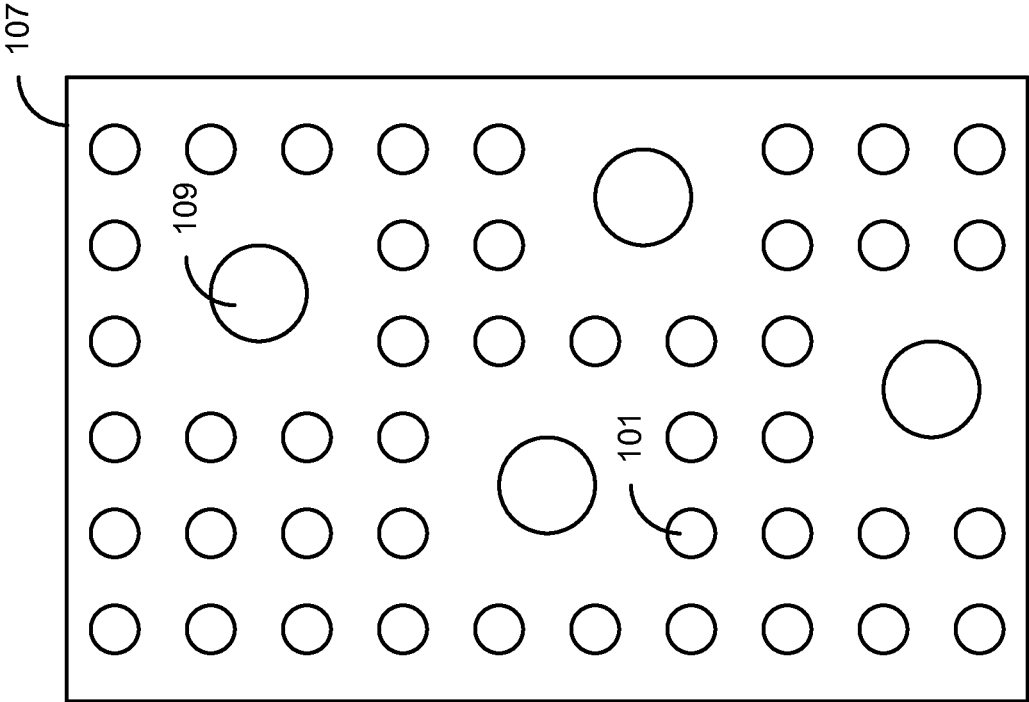


FIG. 4A

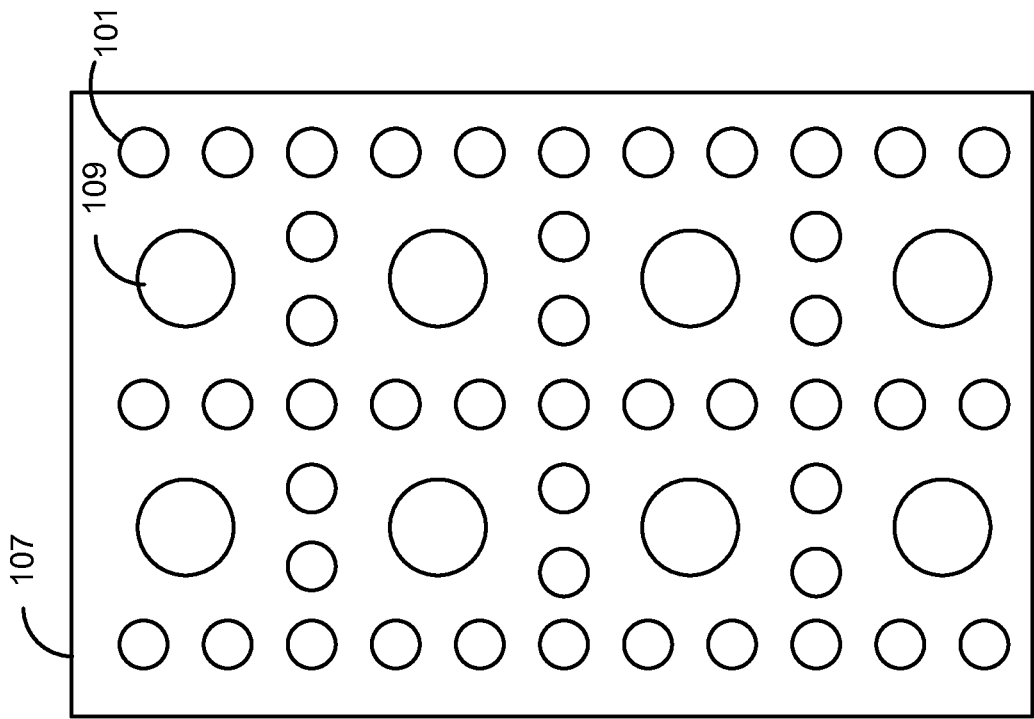


FIG. 4D

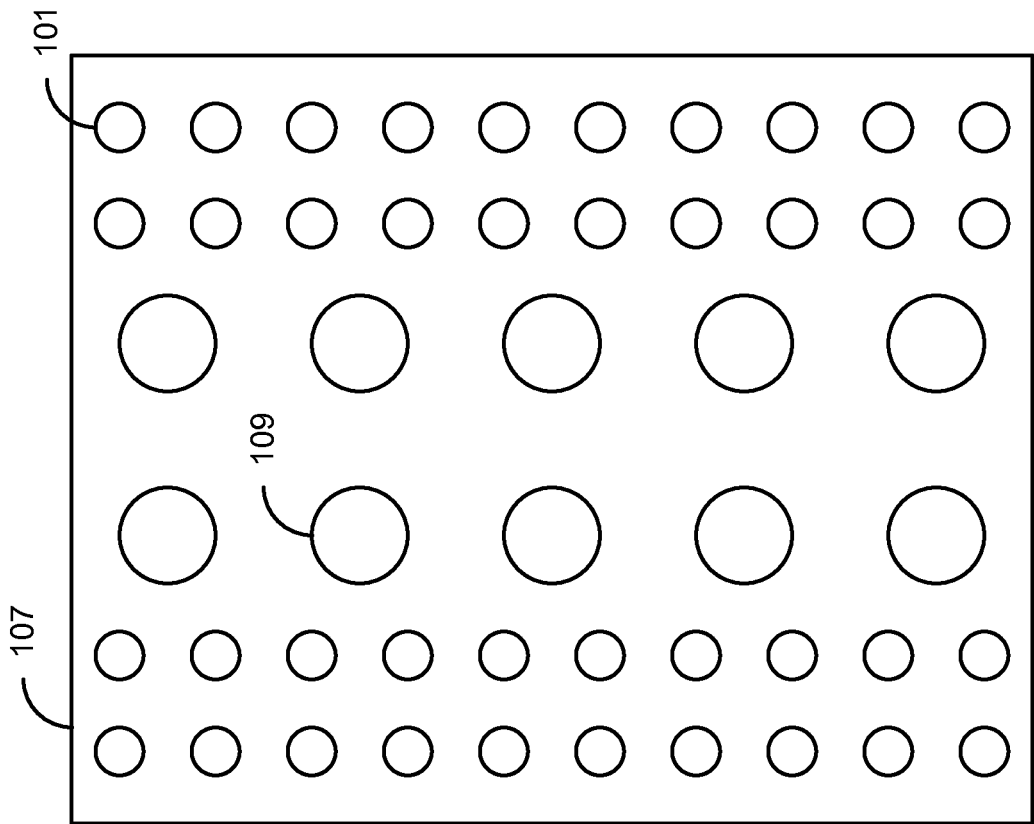
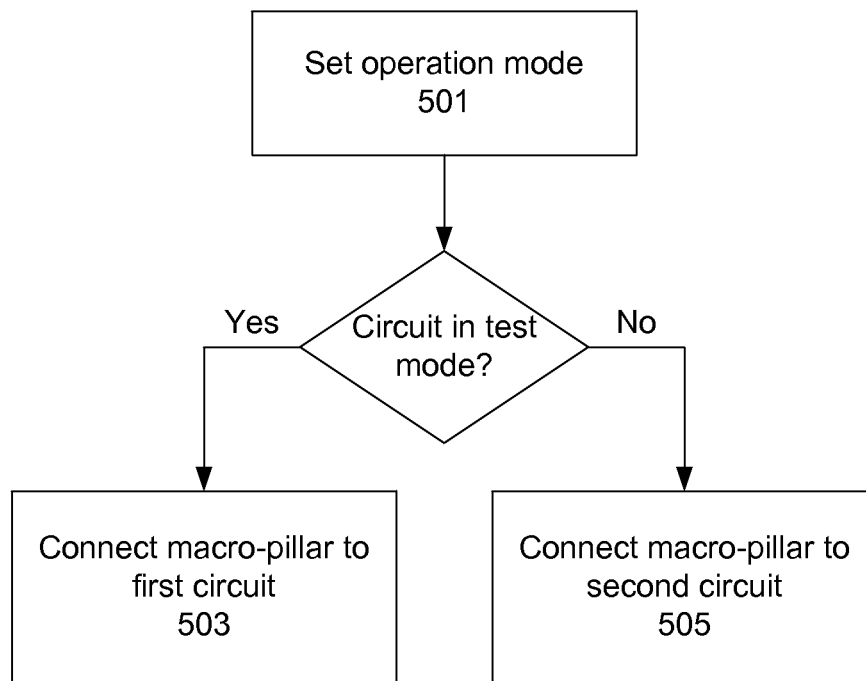
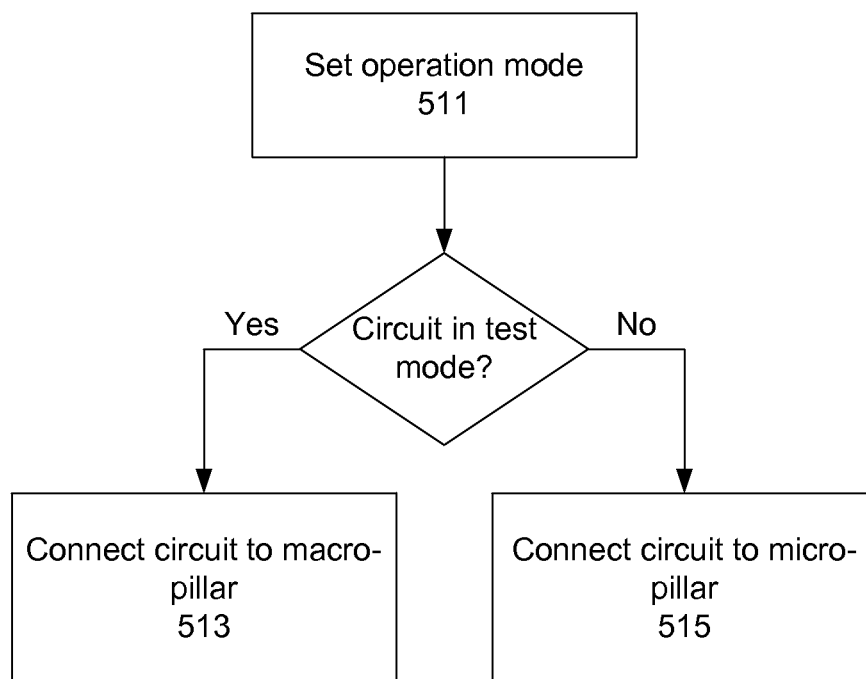
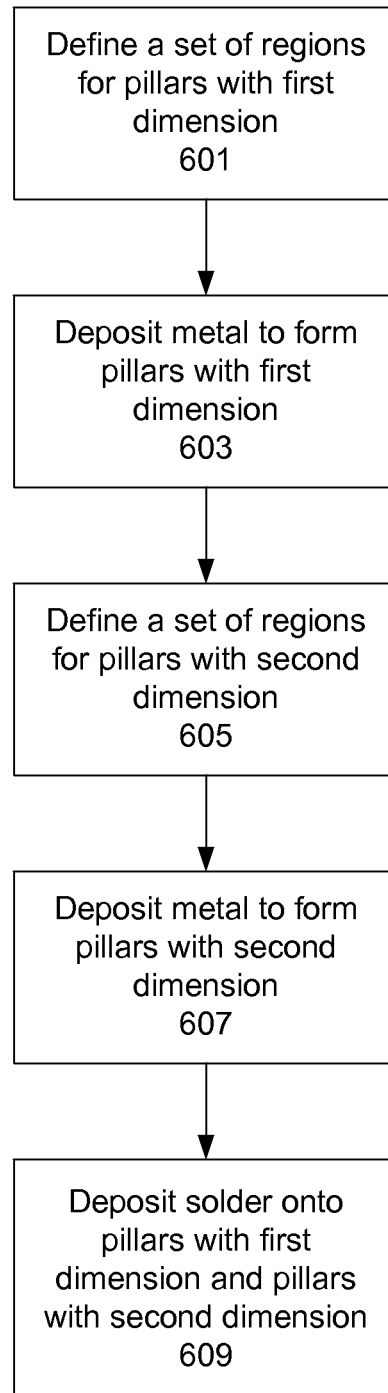


FIG. 4C

**FIG. 5A****FIG. 5B**

**FIG. 6**

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MIXED-SIZED PILLARS THAT ARE PROBEABLE AND ROUTABLE

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/825,984, filed May 21, 2013, which is incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to integrated circuits. More particularly, it relates to probeable and routable interfaces for integrated circuits.

2. Description of the Related Art

Integrated circuits may interface to external circuitry using a number of different techniques. For example, a flip chip integrated circuit may interface to external circuitry using small solder balls attached to micro-pillars located on the integrated circuit. Integrated circuits may be tested before being packaged or bonded to other integrated circuits. However, as the micro-pillars become smaller in size, the cost for probing and testing the integrated circuit increases. Thus, there is a need for better approaches to the use of micro-pillars.

SUMMARY OF THE INVENTION

The present invention overcomes the limitations of the prior art by including larger diameter pillars (referred to as “macro”-pillars) which have similar heights as the smaller micro-pillars. During testing of the integrated circuit, the macro-pillars can be probed at a lower cost since they are larger than the micro-pillars. Since the macro-pillars have similar heights as the micro-pillars, they can be used not only for testability but also as an electrical interface to the integrated circuit during regular operation.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention has other advantages and features which will be more readily apparent from the following detailed description of the invention and the appended claims, when taken in conjunction with the accompanying drawings, in which:

FIG. 1A is a cross sectional side view of an integrated circuit being probed with a probe card, according to one embodiment of the invention.

FIG. 1B is a cross sectional side view of an integrated circuit with macro-pillars and micro-pillars, shown during testing of the integrated circuit, according to one embodiment of the invention.

FIG. 1C is a cross sectional side view of an integrated circuit with macro-pillars and micro-pillars having the similar total height, according to one embodiment of the invention.

FIG. 2 is a cross sectional side view of the integrated circuit of FIG. 1, shown during operation of the integrated circuit, according to one embodiment of the invention.

FIG. 3A is a diagram of an integrated circuit with a macro-pillar switchably connected to multiple circuits, according to one embodiment of the invention.

FIG. 3B is a diagram of an integrated circuit with a circuit switchably connected to a macro-pillar and a micro-pillar, according to one embodiment of the invention.

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FIG. 4A is a top view of an integrated circuit with macro-pillars randomly arranged across the surface of the integrated circuit, according to one embodiment of the invention.

FIG. 4B is a top view of an integrated circuit with macro-pillars located around the perimeter of the integrated circuit, according to one embodiment of the invention.

FIG. 4C is a top view of an integrated circuit with macro-pillars located in a center region of the integrated circuit, according to one embodiment of the invention.

FIG. 4D is a top view of an integrated circuit with macro-pillars periodically arranged across the surface of the integrated circuit, and with micro-pillars interspersed between macro-pillars, according to one embodiment of the invention.

FIG. 5A is a flow diagram of a process for operating an integrated circuit, according to one embodiment of the invention.

FIG. 5B is a flow diagram of a process for interfacing a circuit of an integrated circuit, according to one embodiment of the invention.

FIG. 6 is a flow diagram of a fabrication process for fabricating an integrated circuit with macro-pillars and micro-pillars, according to one embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The Figures (FIGS.) and the following description relate to preferred embodiments by way of illustration only. It should be noted that from the following discussion, alternative embodiments of the structures and methods disclosed herein will be readily recognized as viable alternatives that may be employed without departing from the principles of what is claimed.

Reference will now be made in detail to several embodiments, examples of which are illustrated in the accompanying figures. It is noted that wherever practicable similar or like reference numbers may be used in the figures and may indicate similar or like functionality. The figures depict embodiments of the disclosed system (or method) for purposes of illustration only. Alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles described herein.

FIG. 1A illustrates an integrated circuit 107 being probed for testing, according to one embodiment of the invention. In the example of FIG. 1, integrated circuit 107 is being probed using a probe card 120. Probe card 120 is used to simultaneously probe multiple contacts 130 of the integrated circuit 107. Probe card 120 may, for example, be used to connect the integrated circuit 107 to a tester, such as an automated test equipment (ATE) (not shown).

The ATE sends signals to integrated circuit 107 and receives the outputs generated by integrated circuit 107, via the probe card 120. ATE may also compare the received output to an expected output and determine whether integrated circuit 107 is working properly. In some embodiments, ATE sends a power supply signal, a ground signal, and multiple test signals. Test signals may for example, be a digital signal or an analog signal.

Probe card 120 includes multiple probes 125. Each probe 125 is configured to provide electrical connection to a contact 130 of integrated circuit 107. Depending on the size of contacts 130, probes 125 may, for example, be needle probes, vertical probes, or micro electro-mechanical system (MEMS) probes.

Although in the example of FIG. 1A, a probe card 120 with five probes is used to test integrated circuit 107, any number of probe tips may be used for testing integrated circuit 107. In

some embodiments, a probe card **120** tests one integrated circuit die. In other embodiments, a probe card **120** may test an entire wafer, or a portion of a wafer containing multiple integrated circuits **107**.

The probe card and probe type used for testing a specific integrated circuit depends on the size of the contacts **130** of the integrated circuit **107**. For instance, an integrated circuit **107** that has contacts **130** with a pitch of 80 μm may be tested using a probe card with vertical probes, whereas an integrate **107** that has contacts **130** with a pitch of 40 μm may be tested using a probe card with MEMS probes. As the dimension of contacts **130** reduces, the price of the probe card **120** and probes **125** used for testing integrated circuit **107** increases, increasing the price of integrated circuit **107**.

In FIG. 1A, the contacts **130** are all the same size. They could be implemented as pillar-type contacts. As the number of contacts increases, the size of the contacts and the spacing between contacts will decrease. This would require a probe structure **120** that was similar in size and density to the pillars **130**. Since the pillars **130** can be quite small and densely packed, such a probe device can be expensive to manufacture and maintain.

One alternative is to provide additional larger size test pads strictly for the purposes of testing. This technique reduces the cost of probing and testing the integrated circuit since the testing can be performed on the larger test pads using inexpensive equipment. However, the larger test pads take up space. In addition, because the test pads typically are flush with the surface of the integrated circuit, it is difficult to make electrical connections to both the test pads and to the pillar contacts. Therefore, the test pads cannot be easily used as an electrical interface to the integrated circuit.

FIG. 1B is a cross sectional side view of an integrated circuit **107** with both smaller size pillars **101** and larger size pillars **109**, which will be referred to as micro-pillars and macro-pillars, respectively. The macro-pillars **109** have similar heights as the micro-pillars **101**, but the macro-pillars **109** cover a larger area. Since the macro-pillars **109** are larger in area than the micro-pillars **101**, they can be used to reduce the cost of testing the integrated circuit, as shown in FIG. 1B. Since the macro-pillars **109** have similar heights as the micro-pillars **101**, they can also be used as an electrical interface to the integrated circuit **107**, as shown in FIG. 2.

In FIG. 1B, a test probe **105** makes contact with the macro-pillar **109**. This provides the electrical interface to test the integrated circuit. Since the macro-pillar **109** is larger than the micro-pillars **101**, the test probe **105** can also be larger which makes it less expensive and more robust.

In FIG. 2, the integrated circuit **107** is flip chip bonded to an external device **201** to create a composite integrated circuit structure. Examples of device **201** include other integrated circuits, in addition to interface structures such as interposers. Since the macro-pillars **109** have similar heights as micro-pillars **101**, the macro-pillars **109** and micro-pillars **101** can all be used to provide electrical interfaces to the integrated circuit **107**. The larger size of the macro-pillars **109** makes them especially suitable for certain types of interfaces, such as power distribution.

If the macro-pillars **109** are both probeable (i.e., used for testing) and routable (i.e., used as an electrical interface during regular operation), then the macro-pillars typically will be switchably connectable to different circuits on integrated circuit **107**. Connection to one set of circuits will be made during testing (referred to as testing circuitry). Connection to another set of circuits will be made during regular operation (referred to as operational circuitry).

FIG. 3A illustrates a diagram of an integrated circuit **107** with a macro-pillar **109** that is switchably connected to multiple circuits of the integrated circuit **107**, according to one embodiment of the invention. Integrated circuit **107** may include a switch **310** and multiple circuits **320A**, **320B**. In some embodiments, switch **310** may be a demultiplexer. Switch **310** receives a signal provided to the integrated circuit through macro-pillar **109** and routes the received signal to either circuit **320A** or circuit **320B**. In some embodiments, switch **310** may route the signal received through macro-pillar **109** to either circuit **320A** or circuit **320B** based on a circuit operation mode signal **315**. For instance, circuit operation mode signal **315** may be set to a first value when the integrated circuit **107** is being tested, and may be set to a second value when the circuit is in regular operation.

In some embodiments, circuit operation mode signal **315** may be selected from more than two values. For instance, circuit operation mode signal **315** may be set to a first value when the integrated circuit **107** is in regular operation, a second value to connect macro-pillar **109** to a first test circuit, a third value to connect macro-pillar **109** to a second test circuit, and a fourth value to connect macro-pillar **109** to a third test circuit.

In some embodiments, the value of circuit operation mode signal **315** may be set during an initialization step of a test for circuit **107**. In one embodiment, the circuit operation mode signal **315** may be received through a macro-pillar. The circuit operation mode signal **315** may, for example, be stored in a register. In another embodiment, a circuit operation mode detector circuit (not shown) may set the circuit operation mode signal **315** based on whether a signal received through a micro-pillar **101**. For instance, if a signal is received through micro-pillar **101**, circuit operation mode detector circuit may set the circuit operation mode signal **315** to regular operation. Alternatively, if a signal is not received through micro-pillar **101**, the circuit operation mode detector circuit may set the circuit operation mode signal **315** to testing mode.

Macro-pillar **109** may be switchably coupled to multiple circuits **320A**, **320B**. Each circuit **320A**, **320B** may also be coupled to different micro-pillars **101** for independently interfacing each circuit **320A**, **320B** during normal operation. For instance, circuit **320A** may be coupled to a first micro-pillar and circuit **320B** may be coupled to a second micro-pillar. During testing of the integrated circuit **107**, depending on the value of the circuit operation mode signal **315**, either circuit **320A** or circuit **320B** may be interfaced through macro-pillar **109**. Alternatively, during normal operation, circuit **320A** may be interfaced through the first micro-pillar, and circuit **320B** may be interfaced through the second micro-pillar.

FIG. 3B illustrates a diagram of an integrated circuit **107** with a macro-pillar **109** and a micro-pillar **101** coupled to a selector **330**, according to one embodiment of the invention. Selector **330** may select a signal for routing to circuit **320** based on a circuit operation mode signal **315**. For instance, selector **315** may select a signal received through macro-pillar **109** when circuit operation mode signal **315** is set to a first value indicating the integrated circuit **107** is being tested, and may select a signal received through micro-pillar **101** when circuit operation mode signal **315** is set to a second value indicating the integrated circuit **107** is in normal operation.

In more detail, a micro-pillar **101** is a pillar-shaped structure that provides an electrical interface between an integrated circuit and an external circuit. In some embodiments, the micro-pillar **101** comprises a copper pillar **113** capped by a solder ball **111**. The size of micro-pillars varies depending

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on the technology node being used. In some embodiments, micro-pillars may have a circular cross section. In other embodiments, micro-pillars may have an octagonal cross section. Embodiments of micro pillars may have an aspect ratio of 1 to 1 (height is equal to diameter). For example, a micro-pillar might be 20 μm in diameter and 20 μm in height. In some embodiments, a pillar-shaped structure is considered to be a micro-pillar if the diameter is smaller than 45 μm .

Macro-pillars 109 are similar to micro-pillars 101 but cover a larger area. If both the micro-pillars 101 and macro-pillars 109 are cylindrical, then they will have similar heights but the macro-pillars 109 will have larger diameters. For example, a macro-pillar might be 90 μm in diameter and 20 μm in height. Macro-pillars 109 may also comprise a copper post 119 capped by solder 117 (although it may not be a solder ball). Solder reflow techniques can be used to make connections to the solder portions of both the macro-pillars 109 and the micro-pillars 101. In some embodiments, micro-pillars 101 and macro-pillars 109 are designed to have similar heights after the reflow process. In some embodiments, the micro-pillars 101 and/or the macro-pillars 109 have a circular cross section. In other embodiments, the micro-pillars 101 and/or the macro-pillars 109 have an octagonal cross section. In yet other embodiments, the micro-pillars 101 and/or the macro-pillars 109 may have a cross section with any other geometrical shape, such as a square, a hexagon, and the like.

Since the rate of deposition and/or electroplating of the metal that forms micro-pillars 101 and macro-pillars 109 depends on the diameter of the pillars, in some cases, micro-pillars 101 and macro-pillars 109 are formed in two different steps. In one embodiment, the micro-pillars 101 are formed before forming the macro-pillars 109. In other embodiments, the macro-pillars 109 are formed before forming the micro-pillars 101. In yet other embodiments, if the rate of deposition and/or electroplating is the same, both micro-pillars and macro-pillars may be formed at the same time.

In some embodiments, as illustrated in FIG. 1C, copper pillars 113 of micro-pillars 101 are of different height than copper pillars 119 of macro-pillars 109 to compensate for a height difference of solder balls 111 of micro-pillars 101 and solder balls 117 of macro-pillars 109. The height of solder balls 111, 117 may depend on the diameter of micro-pillars 101 and macro-pillars 109. The height of copper pillars 113 and copper pillars 119 may be adjusted so that the total height of micro-pillars 101 and the total height of macro-pillars 109 are substantially equal.

For example, to form the micro-pillars 101 and macro-pillars 109 of integrated circuit 107, a photolithography step might first define the footprints of the micro-pillars 101. An electroplating process deposits a copper layer in the footprint areas, thus forming the micro-pillars 101. The masking material is removed and a second photolithography process then defines the footprints of the macro-pillars 109. A second electroplating process deposits a copper layer forming the macro-pillars 109.

In one embodiment, the macro-pillars 109 can be located anywhere on the surface of the integrated circuit 107. In other embodiments, the macro-pillars are confined to certain locations (e.g., to the center, or to the perimeter) of the integrated circuit 107.

FIG. 4A-4D are top views showing different arrangements of macro-pillars and micro-pillars, according to different embodiments of the invention. In FIG. 4A, macro-pillars 109 are placed randomly across the surface of the integrated circuit 107.

In FIG. 4B, macro-pillars 109 are located around the perimeter of the integrated circuit 107. For example, core

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devices may be located in the center of the device and it may be beneficial to interface core devices with micro-pillars 101. For instance, micro-pillars 101 may add less parasitic capacitance, compared to macro-pillars, to the input of the circuit being interfaced. In addition, macro-pillars that are located in the perimeter of the integrated circuit may be used to connect power supply and ground signals.

In FIG. 4C, macro-pillars 109 are located in a center region of the integrated circuit 107. For example, the configuration of FIG. 4C might be used if core devices to be tested are located in the center region and I/O devices that require less or no testing are located around the perimeter of the integrated circuit 107.

In FIG. 4D, macro-pillars 109 are periodically arranged across the surface of the integrated circuit 107, and micro-pillars 101 are interspersed between the macro-pillars. For instance, macro-pillars 109 may be spread across the surface of the integrated circuit 107 based on a pitch of the probe card that will be used for testing the integrated circuit. Since micro-pillars 101 can have a smaller pitch than macro-pillars 109, one or more micro-pillars may be placed between two macro-pillars 109, where otherwise there would be an empty space.

In some embodiments, the location of the macro-pillars 109 is determined based on available probe cards that can be used to test the integrated circuit 107. In other embodiments, the location of the macro-pillars might be determined by the integrated circuit fabrication facility to increase the manufacturability and/or the mechanical properties of the integrated circuit 107.

FIG. 5A illustrates a flow diagram of a process for operating an integrated circuit (such as shown in FIG. 3A), according to one embodiment of the invention. An operation mode for the integrated circuit 107 is set 501. For instance, the operation mode may indicate that the integrated circuit is in test mode or normal operation mode. If the operation mode indicates that the integrated circuit is being operated in test mode, macro-pillar 109 is connected 503 to a first circuit 320A used for testing. The first circuit may, for example, be a test circuit. If the operation mode indicates that the integrated circuit is being operated in normal operation mode, macro-pillar 109 is connected 505 to a second circuit 320B used for normal operation.

FIG. 5B illustrates a flow diagram of a process for interfacing a circuit of an integrated circuit (such as shown in FIG. 3B), according to one embodiment of the invention. An operation mode for the integrated circuit 107 is set 511. If the operation mode indicates that the integrated circuit is being operated in test mode, circuit 320 is connected 513 to a macro-pillar 109. If the operation mode indicates that the integrated circuit is being operated in normal operation mode, circuit 320 is connected 515 to micro-pillar 101.

FIG. 6 is a flow diagram of a process for fabricating an integrated circuit with macro-pillars and micro-pillars, according to one embodiment of the invention. A first set of regions for forming pillars with a first dimension is defined 601 on integrated circuit 107. The regions may be formed using a photolithographic process. Metal is deposited 603 on the defined first set of regions to form pillars with first dimension. In one embodiment, the metal deposition process may be an electroplating process. In other embodiments, other metal deposition process, such as vapor metal deposition, metal sputter deposition, may be used to form the pillars.

A second set of regions for forming pillars with a second dimension is defined 605 on integrated circuit 107. Metal is deposited 607 on the defined second set of regions to form pillars with second dimension. In some embodiments, pillars

with first dimension are macro-pillars **107** and pillars with second dimension are micro-pillars **101**. In other embodiments, pillars with first dimension are micro-pillars **101** and pillars with second dimension are macro-pillars **107**. Solder is deposited **609** onto pillars with first dimension and pillars with second dimension.

Although the detailed description contains many specifics, these should not be construed as limiting the scope of the invention but merely as illustrating different examples and aspects of the invention. It should be appreciated that the scope of the invention includes other embodiments not discussed in detail above. Various modifications, changes and variations which will be apparent to those skilled in the art may be made in the arrangement, operation and details of the method and apparatus of the present invention disclosed herein without departing from the spirit and scope of the invention as defined in the appended claims. Therefore, the scope of the invention should be determined by the appended claims and their legal equivalents. Furthermore, no element, component or method step is intended to be dedicated to the public regardless of whether the element, component or method step is explicitly recited in the claims.

In the claims, reference to an element in the singular is not intended to mean "one and only one" unless explicitly stated, but rather is meant to mean "one or more." In addition, it is not necessary for a device or method to address every problem that is solvable by different embodiments of the invention in order to be encompassed by the claims.

What is claimed is:

1. An integrated circuit operable in either a test mode or a normal operation mode, the integrated circuit comprising:
 - a plurality of micro-pillars attached to a surface of the integrated circuit, the micro-pillars comprising copper pillars capped by solder;
 - a plurality of macro-pillars also attached to the surface of the integrated circuit, the macro-pillars comprising copper pillars capped by solder, each macro-pillar covering a larger area than each micro-pillar, wherein the macro-pillars and the micro-pillars have substantially similar heights; and
 - the macro-pillars and the micro-pillars providing an electrical interface to the integrated circuit, responsive to the integrated circuit being in normal operation mode; and
 - the macro-pillars providing an electrical interface to the integrated circuit, responsive to the integrated circuit being in test mode.
2. The integrated circuit of claim **1**, wherein the copper pillars of the micro-pillars and the copper pillars of the macro-pillars are formed by electroplating.
3. The integrated circuit of claim **1**, wherein the copper pillars of the micro-pillars are formed independently of the copper pillars of the macro-pillars.
4. The integrated circuit of claim **1**, further comprising:
 - a switch, one of the macro-pillars coupled to the switch, the switch configured to couple the macro-pillar to a first circuit of the integrated circuit responsive to the integrated circuit being in test mode and to couple the macro-pillar to a second circuit of the integrated circuit responsive to the integrated circuit being in normal operation mode.
5. The integrated circuit of claim **1**, further comprising:
 - a selector having two inputs, one of the macro-pillars coupled to one of the inputs and one of the micro-pillars coupled to the other of the inputs, the selector configured to couple the macro-pillar to a first circuit of the integrated circuit responsive to the integrated circuit being

in test mode and to couple the micro-pillar to the first circuit of the integrated circuit responsive to the integrated circuit being in normal operation mode.

6. The integrated circuit of claim **1** wherein the micro-pillar has a diameter smaller than 45 μm .
7. The integrated circuit of claim **1** wherein the macro-pillar has a diameter greater than 90 μm .
8. The integrated circuit of claim **1**, wherein the macro-pillars are probeable using a vertical probe card.
9. The integrated circuit of claim **1**, wherein the plurality of macro-pillars and the plurality of micro-pillars are randomly arranged across the surface of the integrated circuit.
10. The integrated circuit of claim **1**, wherein the plurality of macro-pillars are arranged around a perimeter of the surface of the integrated circuit.
11. The integrated circuit of claim **1**, wherein the plurality of macro-pillars are arranged in a central region of the surface of the integrated circuit.
12. The integrated circuit of claim **1**, wherein the plurality of macro-pillars are periodically arranged across the surface of the integrated circuit, and at least one or more micro-pillars from the plurality of micro-pillars are arranged in between two macro-pillars of the plurality of macro-pillars.
13. The integrated circuit of claim **1**, wherein at least one of the plurality of macro-pillars is for supplying power to the integrated circuit.
14. A composite integrated circuit structure comprising:
 - an integrated circuit having a first surface, with a plurality of micro-pillars and a plurality of macro-pillars attached to the first surface, the macro-pillars switchably connectable to testing circuitry on the integrated circuit; and
 - a device having a second surface, the micro-pillars and macro-pillars contacting the second surface, the micro-pillars and macro-pillars configured to provide an electrical interface between the integrated circuit and the device.
15. The composite integrated circuit structure of claim **14**, wherein the device is a silicon interposer, and wherein the silicon interposer comprises a first plurality of contact pads and a second plurality of contact pads, each contact pad of the second plurality of contact pads covering a larger area than each contact pad from the first plurality of contact pads.
16. The composite integrated circuit structure of claim **14**, wherein the device is configured to have a third surface, the third surface configured to provide an electrical interface between the device and a printed circuit board.
17. The composite integrated circuit structure of claim **14**, wherein the plurality of micro-pillars and the plurality of macro-pillars of the integrated circuit are used for flip chip bonding the integrated circuit to the device.
18. A method for manufacturing an integrated circuit, the method comprising:
 - defining a first set of regions with a first dimension;
 - depositing metal on the defined first set of regions to form a first set of pillars with the first dimension;
 - after depositing metal on the defined first set of regions:
 - defining a second set of regions with a second dimension, the second dimension different than the first dimension, and
 - depositing metal on the defined second set of regions to form a second set of pillars with the second dimension; and
 - depositing metal on the first set of pillars and the second set of pillars.